

The Alternative Way to Drive the Automobile Air-Conditioning, Improve Performance, and Mitigate the High Temperature: A Literature Overview

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RESEARCH ARTICLE

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Abstract

Over fuel consumption and increasing in CO₂ emissions are problems as compensation from the imposition of automobile A/C systems. Another problem is the extreme temperature when the car is parked under sunlight so that the thermal load becomes very large when A/C is turned on. Therefore, this article presents various methods to overcome the problem. Methods to reduce fuel consumption and to reduce CO₂ emissions are done by application of VCC and the absorption system. Potential of turbo A/C system and combining vapor compression and LPG fuel system has also been studied. Potential of turbo A/C system and combining vapor compression and LPG fuel system has also been studied. Related to the mitigating of high temperature inside the car cabin when parked under sunlight, the addition of a ventilator and portable car cooling system is a promising option.

Keywords

automobile A/C, alternative A/C system, high-temperature mitigation

1 Introduction

Air-Conditioning System (A/C system) has a long history for automobile equipment. Before 1940, to stay comfortable and to keep cool in a closed car were done by cranked up and down of side windows for the desired airflow. Another way was done by opening or closing the vents under the dashboard (Bhatti, 1999). In 1940, Packard became the first car manufacturer to offer A/C as an option. The cooling system is located in the trunk and no interior controls. Then in 1969, more than half of all new cars sold were equipped with vapor compression A/C system that can be operated easily (Automobile, 2010). The basic of vapor compression A/C system is presented in Fig. 1 (Daly, 2006).

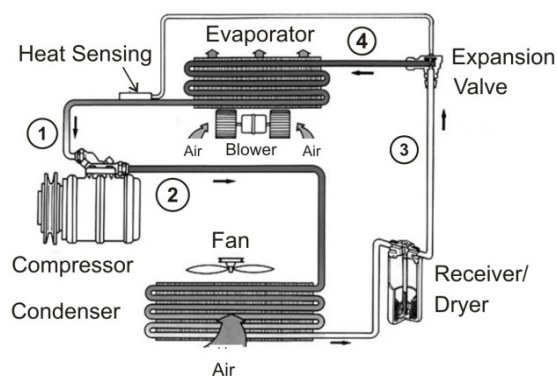


Fig. 1 Basic scheme of vapour compression A/C system

Now, the A/C system has been the main accessories in the automobiles to comfortably. In the passenger or driver cabin, A/C serves for controlling temperature, humidity, air circulation and ventilation, and for cleaning of the air odors, pollutants, dust, etc. The majority of A/C component can regulate themselves based on cabin temperature and refrigerant pressure. On the other hand, the A/C system causes significant power reduction and increases fuel consumption (Benouali et al., 2003; Lee et al., 2013; Kumar et al., 2014) a voluntary agreement has been signed between the European Car Manufacturer Association (ACEA). The impact of A/C system on fuel consumption has two main effects. The first is related to the indirect greenhouse

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effect due to the increase in fuel consumption. The second is linked to the user and market attention to fuel economy (Benouali et al., 2003; Vishweshwara et al., 2013).

Reducing the thermal load of the vehicle interior is essential to improving vehicle fuel economy (Huang et al., 2005). The heaviness of the A/C system is to compensate of the thermal load in the cabin until a comfortable temperature (Fig. 2). In the cold weather, heating the cabin is necessary. Meanwhile, in the hot weather, cooling the cabin is needed.

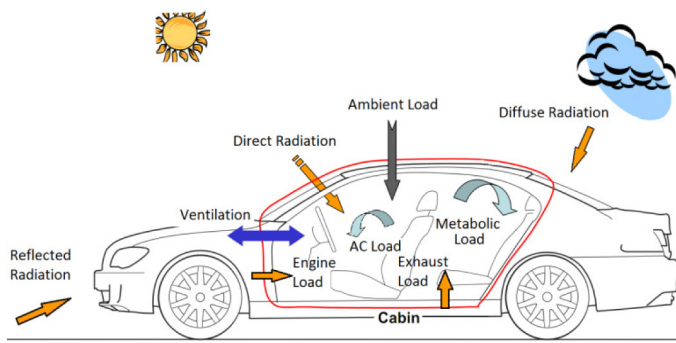


Fig. 2 Heat Balance on Automobile (Fayazbakhsh and Bahrami, 2013)

From Fig. 2, heat balance model in an automobile is formulated in Eq. (1) as follows (Fayazbakhsh and Bahrami, 2013; Vaghela, 2014).

$$\dot{Q}_{AC} = - \left[\dot{Q}_{Met} + \dot{Q}_{Dir} + \dot{Q}_{Dif} + \dot{Q}_{Ref} + \dot{Q}_{Amb} + \dot{Q}_{Exh} + \dot{Q}_{Eng} + \dot{Q}_{Ven} \right] - \left[\frac{(m_a c_a + DTM)(T_i - T_{comf})}{t_c} \right] \quad (1)$$

Where, \dot{Q}_{AC} is the thermal load created by A/C cycle. \dot{Q}_{Met} is the metabolic load. \dot{Q}_{Dir} , \dot{Q}_{Dif} , and \dot{Q}_{Ref} are the direct, diffuse, and reflected radiation loads, respectively. \dot{Q}_{Amb} is an ambient load. \dot{Q}_{Exh} and \dot{Q}_{Eng} are the exhaust and engine loads due to the high temperature of the exhaust gases and the engine. \dot{Q}_{Ven} is the load generated due to ventilation. m_a is the cabin air mass and c_a is the air specific heat. T_i , t_c , T_{comf} are the initial cabin temperature, pull-down constant, and the target comfort temperature, respectively. Finally, DTM is the sum of all the deep thermal masses i.e. the overall thermal inertia of all objects other than air present inside the cabin.

Between 1995 and 1998, the CENERG and ADEME carried out two series of tests to determine excessive fuel consumption due to the A/C operation. Gasoline, diesel without a turbocharger, and diesel with turbocharger engines were tested. The tests have been performed at United Test and Assembly Center (UTAC) facilities under MVEG cycle for two ambient temperatures, 30°C and 40°C. The results studies are presented Table 1 (Benouali et al., 2003).

Table 1 Relative excessive fuel consumption (%) for various cars measured by CENERG and ADEME

Type of Car	Gasoline engine		Diesel engine		Turbo-Diesel engine	
	30 °C	40 °C	30 °C	40 °C	30 °C	40 °C
Cycle	30 %	38 %	26 %	28 %	40 %	42 %
Urban	31 %	38 %	26 %	28 %	40 %	42 %
Extra Urban	16 %	20 %	12 %	15 %	28 %	33 %

Source: Benouali et al. (2003)

Meanwhile, The National Renewable Energy Laboratory (NREL) reported that the excessive fuel consumption due to A/C systems were up to 35%. Benouali (2003) conducted a series of tests to investigate over fuel consumption with different types of cars and weather conditions. Two series of tests performed in the climatic chamber and on the test-bench show that the over fuel consumption due to the A/C operation is 1.0 to 2.45 l/100 km (21 to 53%) along the European MVEG cycle.

In recent years, high temperatures in the car interior have been a concern of many researchers. When the car is parked in direct sunlight, the temperature in the car's cabin will increase up to 80 °C (Al-Kayiem et al., 2010). The highest temperature is recorded at the dashboard, which can reach up to 87.5°C (Jasni and Nasir, 2012). In other locations of the test, the temperature inside a car can reach up to 62 °C at 01:00 pm (Basar et al., 2013). These conditions not only cause discomfort but also accelerate damage to the interior components (Al-Kayiem et al., 2010; Manning and Ewing, 2009). In addition, every year hundreds of children died and pain due to the extreme temperatures inside the vehicle (Mezrhah and Bouzidi, 2006). Therefore, this article presents an overview of some alternative way to reduce fuel consumption, to drive the A/C system, and to mitigate the high temperature inside the car during the car is parking in the direct sunlight.

2 Methods to Reduce Fuel Consumption

Various methods have been developed by researchers to reduce over fuel consumption due to the A/C operation. One of which was done by applying the Variable Capacity Compressor (VCC) (Wang et al., 2009). The VCC produces higher COP than Fixed Capacity Compressor (FCC) in the high-speed compressor. Although VCC operation is slightly poorer than FCC in the low-speed compressor (Alkan and Hosoz, 2010). The performance of VCC associated with fuel consumption and CO₂ emissions have also been studied by Zima et al. (2014). For the pneumatic controlled VCC, the cycling of the compressor enables Series Reheat Reduction, which provides 9 liters of gasoline saving per year and reduces CO₂ up to 1.0 g/km. For the electronically controlled variable compressor, selective cycling allows the compressor to be off for an extended period of time, resulting in 3.5 liters of additional savings per year and reducing CO₂ in 0.4 g/km. The pneumatic VCC construction is presented in Fig. 3 (Zima et al., 2014).

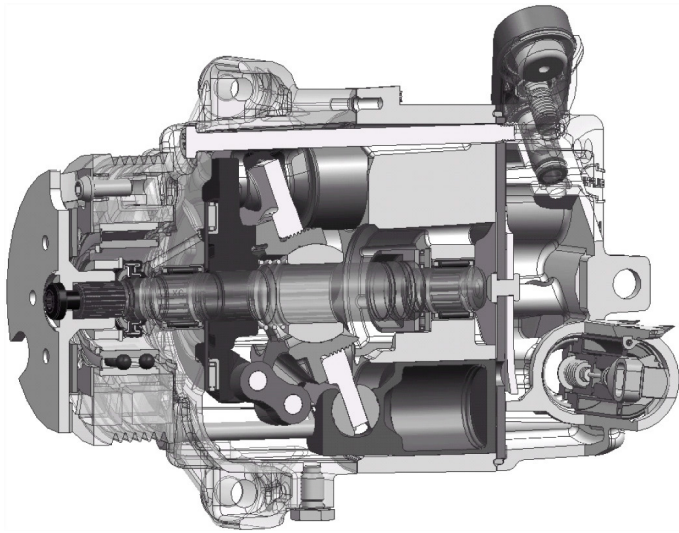


Fig. 3 Pneumatic Variable Displacement Compressor

3 The Alternative Methods to Drive the A/C Systems

The automobile A/C systems majority work by the vapor compression cycle. However, requirements on engine efficiency, it has been developed in the absorption system. Vicatos et al. (2008) utilizing the thermal energy of the exhaust gas to powering the A/C absorption systems in passenger cars. This work has been used although only produce a small COP, between 0.8 and 0.9. Absorption A/C system was also studied by Tiwari and Parishwad (2012). The system is capable of producing a cooling effect by 1 to 1.2 kW, with COP value between 0.4 and 0.45. Other study on the absorption system is also conducted by Shrotri (2015). The basic scheme of the absorption A/C system is presented in Fig. 4. Recently, absorption system is also developed on triple fluid (Krishnadasan et al., 2014).

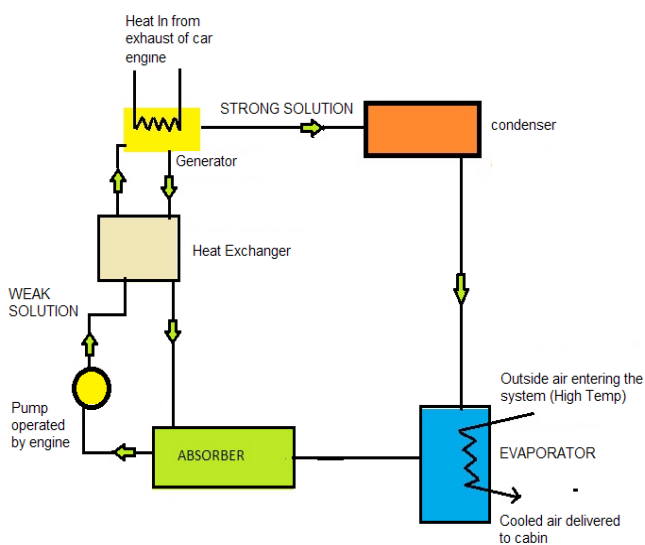


Fig. 4 Basic arrangement of the absorption A/C system (Shrotri, 2015)

Another absorption A/C system was introduced by Vasta et al. (2012) with water chiller system that utilizes the coolant loop as the power supply (Fig. 5). Testing is done by installing the adsorption chiller on the truck cabin to prove the function of the prototype. This system is able to produce 9 °C of air that flows across the evaporator with the cooling effect are expected up to 2 kW.

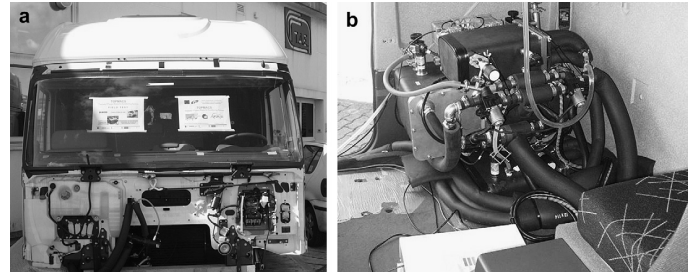


Fig. 5 a, b. The adsorption A/C system installed on a truck cabin IVECO Stralis (Vasta et al, 2012)

A new method to drive the A/C compressor in order to reduce the engine load was carried by the turbo system (Fig. 6). Kinetic energy and pressure of the exhaust gas are used to rotate the turbo propeller blades, and then to turn the A/C compressor by a magnetic gear (Kumar et al., 2014). The major advantage of this method is that it can be applied easily for use in low power engine and can ensure a high-capacity. This method offers the utilization of exhaust gas that is better and can reduce fuel consumption.

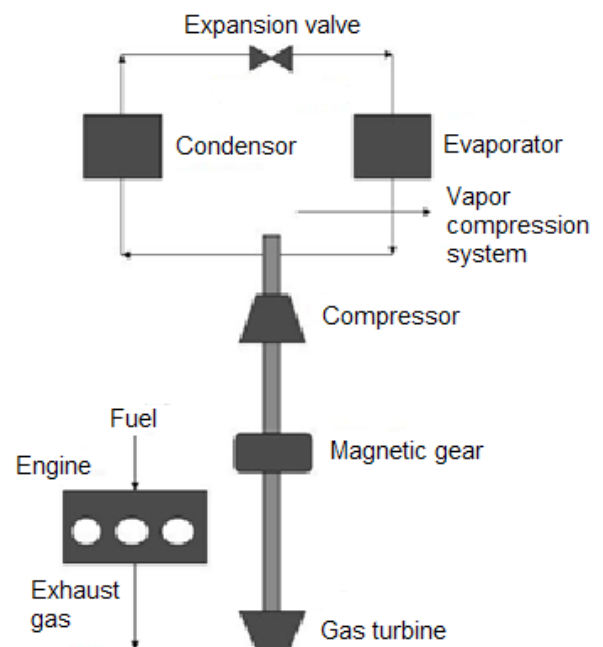


Fig. 6 Concept of Turbo A/C (Kumar et al., 2014) exempting the use of belts and pulleys. This paper validates the use of gas turbines as a power input for AC compressor using Computational Fluid Dynamics (CFD)

Recently, Setiyo et al. (2016) have been investigating the potential cooling effect of LPG-fueled vehicles to cool the car's cabin. A numerical simulation performed to calculate the potential heat absorption on LPG vaporizer device. Cooling effect potential that can be harvested from the 2000 cc engine is estimated more than 1 kW at 3000 rpm. Nevertheless, the results of this simulation have not been carried out with experimental studies to determine the actual cooling capacity that can be harvested.

4 Alternative Methods to Reduce Car Cabin Temperature

In the last decade, the high temperatures inside car's cabin when the car is parking in direct sunlight have been a serious concern. High thermal load after the car is parked in direct sunlight has become specific targets to be reduced. It also has been a research program by SAE, announced in April of 2004 (Rugh et al., 2007).

Various methods were introduced by the researchers to reduce the cabin temperature. Basar et al. (2013) introduced a technology to mitigate high temperature inside the cabin by applying a portable car cooling system (Fig. 7). Portable car cooling system can maintain the temperature inside the car in the range of 25 °C to 30 °C from the initial condition that can reach 70 °C.



Fig. 7 Portable car cooling system (Basar et al., 2013)

Saidur et al. (2009) lowering the cabin temperature by installing a ventilator driven by solar cells Ventilator system has been proven to keep the interior at normal temperature. Decreasing of temperature in the compartment of the car will reduce the energy consumption of the A/C system. In addition, reducing the temperature will inhibit damage to the interior. The same study also conducted by Vishweshwara et al. (2013). Ventilators drove by 10 Watts power motors (Fig. 8). able to lower the cabin temperature by up to 50% of the initial conditions.



Fig. 8 Ventilation system mounted on the rear end of the car (Vishweshwara et al., 2013).

In addition to the ventilator, extreme temperature inside the cabin when parking can be reduced by opening a window or installing reflective glass coating. Color selection of vehicles is also an important consideration (Manning and Ewing, 2009).

5 Indicator of the Several Methods

Some of the methods introduced by the researchers are proven to improve the performance of A/C systems, replacing the vapor compression systems, and mitigate high temperature in the cabin, depending on the case. However, the researchers did not present the same indicators that can be compared. Table 2 shows a summary of the methods and the results of the researchers who studied in this paper.

6 Conclusion

Some technology on automobile A/C system has been developed to reduce fuel consumption and CO₂ emissions. The use of a variable capacity compressor shown has a positive impact. The interesting idea is the utilization of the kinetic energy of the exhaust gas to drive the compressor on turbo A/C system. Other's technology is an alternative system to replace the existing vapor compression system. One of which is the absorption A/C systems by utilizing the thermal energy of exhaust gas, despite producing a low COP. Meanwhile, the extreme temperatures in the cabin while the car is parked in the direct sunlight has become a serious concern. The use of portable car cooling systems and ventilators can increase comfort and reduce the risk of damage to the vehicle interior components. In conclusion, the lower initial temperature will shorten the pull-down time, so the comfortable temperature is quickly achieved. These methods contribute to reducing emissions and fuel consumption, although only in small quantities.

Table 2 Summary of alternative methods to drive the A/C system and to mitigate the high temperature in the cabin

Researcher	Scope and Methods	Car engine condition	Parameters			
			COP	RE (kW)	T _{out evap} (°C)	T _{cabin} (°C)
Vicatos et al., (2008)	Utilizing energy from the exhaust gas as a supplier of heat in the absorption refrigeration system.	Operation	0.08-0.09	2.12	-	-
Tiwari and Parishwad (2012)	Utilizing energy from the exhaust gas as a supplier of heat in the absorption refrigeration system.	Operation	0.4-0.45	1-1.2	-	-
Vasta et al. (2012)	A/C absorption system with water chiller for cooling the truck cabin	Operation	0.25-0.45	1-2.3	8-14	28-36
Kumar et al. (2014)	Converting the kinetic energy of the exhaust gases into useful energy to drive the A/C compressor by turbo system. Exempting the use of belts and pulleys. This paper validates the use of gas turbines as a power input for AC compressor using Computational Fluid Dynamics (CFD).	Simulations	-	-	-	-
Setiyo et al. (2016)	Latent heat of LPG evaporation in the LPG vaporizer device is supplied to the cabin.	Simulations	-	1.3	-	-
Saidur et al. (2009)	Installing ventilator powered by solar cell to reduce the cabin temperature at the time of parking.	Passive	-	-	-	52.1 from 64.5
Vishweshwara et al. (2013)	Installing ventilator powered by solar cell to reduce the cabin temperature at the time of parking.	Passive	-	-	-	43 from 55
Basar et al. (2013)	Adding portable car cooling system to reduce the cabin temperature at the time of parking.	Passive	-	-	-	30 from 70

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